Hydrological Modeling of the Jezero Crater Outlet-Forming Flood

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I. Introduction and Summary

Jezero crater is a site of prime scientific interest because it was a lake early in Mars history [1]. Preserved clay- and carbonate-bearing sedimentary fans [2] on Jezero's western and northwestern margin (Fig. 2) are accessible to future exploration. Geologic context [1] and stratigraphic analysis of the western fan [3] strongly support the interpretation that these fans were deposited as deltas into the lake. This has helped establish Jezero as one of the final candidate landing sites for Mars 2020. The high level of certainty that Jezero was a lake results from the existence of its outlet valley, which required filling of the crater to form [e.g., 1,4]. Here, we specifically focus on how this outlet valley was carved by the dam breach flood that eroded the eastern crater rim. We have completed preliminary modeling in both 1D and 2D of the outlet's formation.

The growth and incision of the breach in this type of dam break is directly coupled to flood discharge [e.g., 5]. For Jezero, the discharge through the breach eventually lacked sufficient energy to erode through the whole crater rim dam, preventing complete drainage of the lake. After the flood, additional incision of the outlet valley is limited to what is possible under more normal fluvial conditions.

Given the observed number of hydrologically open-basin lakes on Mars, basin-breaching floods were a common occurrence [4]. Thus, in addition to being of interest for Jezero, better understanding the character of these floods has broad potential implications for understanding Noachian/Hesperian martian surface hydrology.

We estimate that the peak discharge of the outlet valley-forming flood was ~1-5×10^5 m^3/s, consistent in both the 1D and 2D models. In the parameter space explored to date, it has been hard to reproduce the outlet valley's morphometry from the flood alone, despite this being the most likely geological scenario.

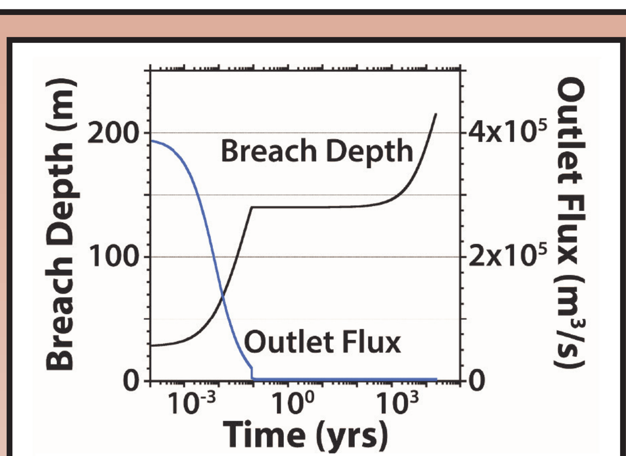


Figure 3. 1D model of the hydrology of Jezero's outlet forming flood using parameters given in Table 1, below. The flux through the outlet is blue, breach depth is black. Note also the log scale of the x-axis.

2. 1D Hydrological Modeling

We constructed a 1D model using equations commonly applied to reconstruct floods from terrestrial dam breach events [5, 6]. Because the growth of the breach and fluid discharge from the lake are coupled by the rate that the breach can erode, we iteratively solve for the evolving topography of the breach and outlet valley depth.

To do so, we specify the initial hydraulic head (lake level and breach depth), grain size (D_{50}, D_{90}), fluid and sediment density (ρ and ρ_s), and critical shear stress for erosion τ_{*cr} (see Table 1). Discharge is calculated as flow over a weir, and we compute erosion, sediment transport, and breach growth by calculating the shear stress on the channel bed [e.g., 6]. The breach width is a fixed parameter in the 1D model. The strength of the crust is controlled by the grain size of transported sediment, while the breach geometry establishes the initial energy available for erosion.

Fig. 3 and Table 1 show examples of our 1D modeling results. In Fig. 3, the outlet breach is eroded ~140 m during the initial flood over the course of days to weeks. Beyond that depth the flood lacked sufficient competency to deepen the breach further and the lake did not fully drain. Incising the total depth of the outlet valley required additional geomorphic work under more normal fluvial conditions.

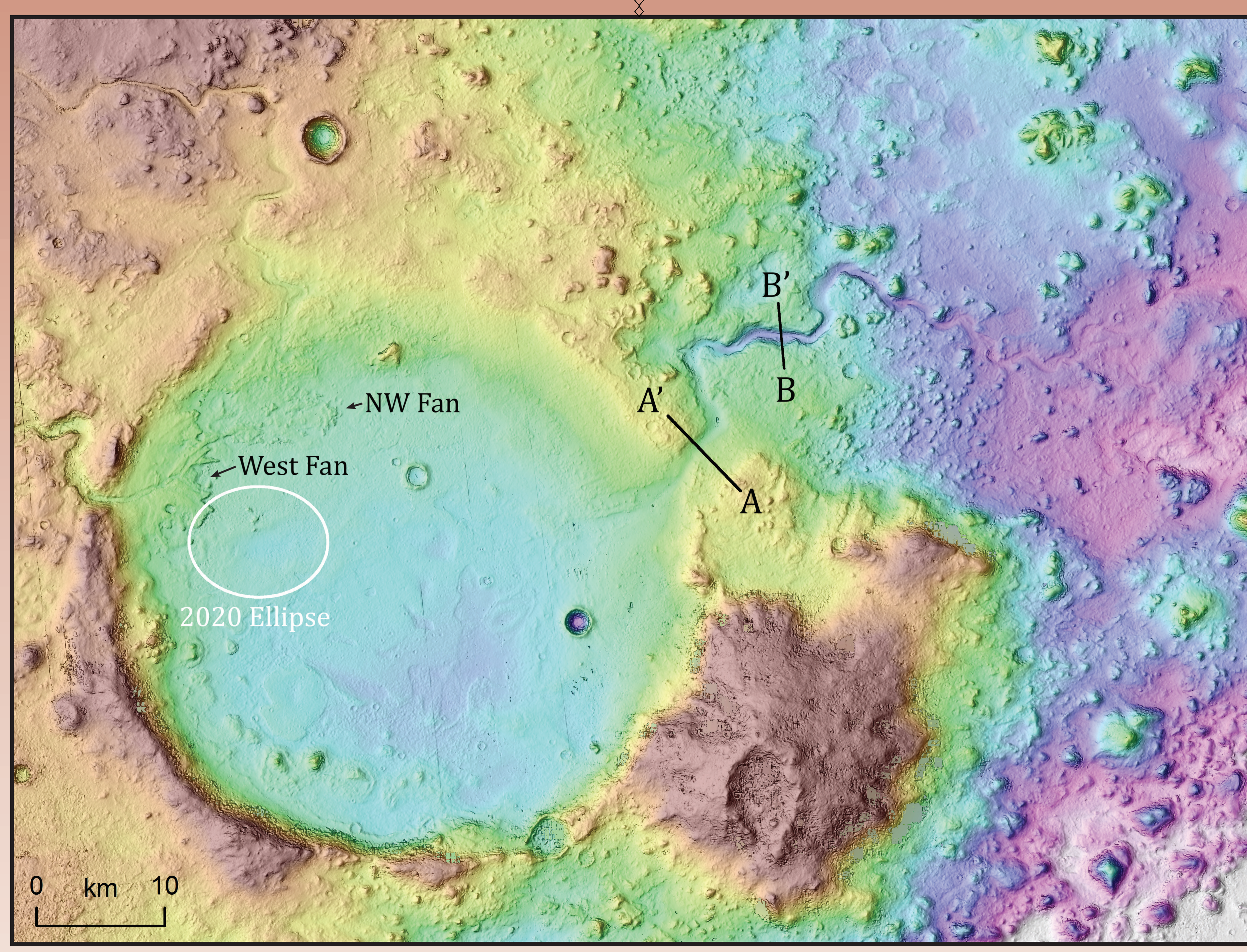
Table 1. Assumed (*italic*) and Output (**bold**) Values for 1D Model

Parameter	Value
Initial Breach (hyraulic head)	*30-40 m*
D_{50}	*0.1-0.5 m*
D_{90}	*1.0-5.0 m*
ρ	*1000 kg/m^3*
ρ_s	*2900 kg/m^3*
τ_{*cr}	*0.06*
Peak Q_w	**3.9–4.7 x 10^5 m^3/s**
Time to erode initial rim	**4.6–32.9 days**
Time to erode outlet valley	**1.9x10^3–2x10^4 yrs**

Figure 1. (Left) Failure of the Teton Dam, June 5, 1976, on the Teton River in Idaho; peak flux was ~60000 m^3/s [7]. The dam failed on initial filling as it was still under construction. (Right) Aftermath of the flood at the dam site. Although the flood had dire consequences for life and property, most of the downstream erosion was of soil; bedrock incision was ~1 m [7]. Note that the total water stored was three orders of magnitude smaller than Jezero.

Figure 2. Jezero Crater (18.5N, 77.5E), Mosaic of CTX DTMs posted at 20 m/px, superposed on a multihillshade of the DTMs, created with the Ames Stereo Pipeline [8,9].

Major features of interest in Jezero are the two deltas on the western and northwestern margin of the crater [1] and the outlet canyon, which was incised up to a depth of ~300m below its surroundings (see Fig. 4).



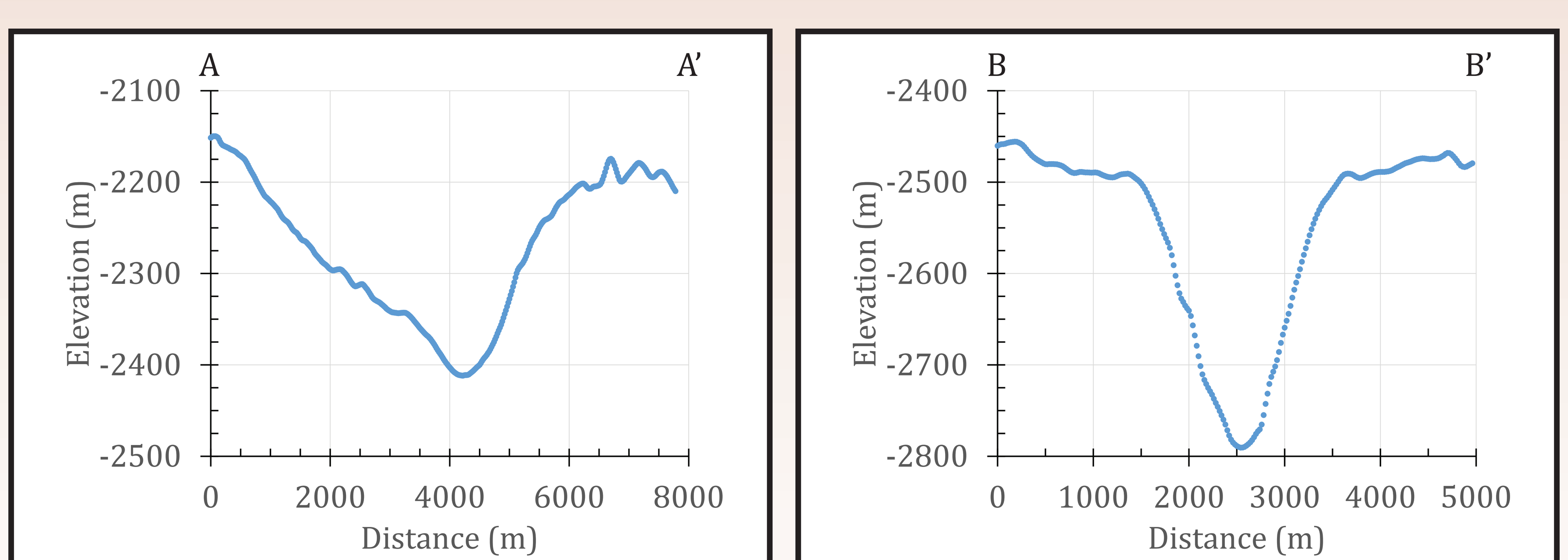


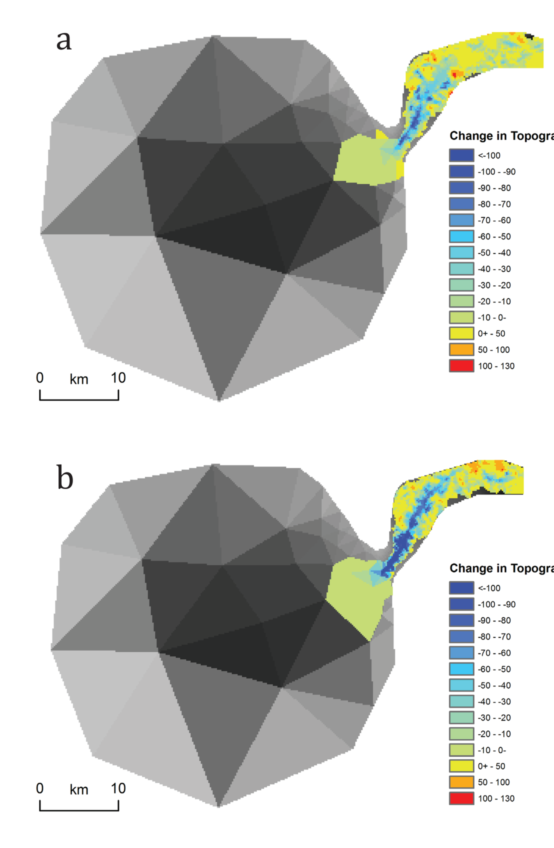
Figure 4. (Left) Profile A-A' across the breach in the eastern rim of Jezero Crater. (Right) Profile B-B' across the Jezero outlet valley, 20 km downstream.

The outlet breach is ~6 km wide and ~200 m deep; the outlet canyon 20 km down valley is ~1 km wide and 300 m deep. Matching this width and depth of the outlet valley downstream of the breach is particularly challenging for the 2D model runs to date, which tend to produce wider and less entrenched valleys (see Fig. 5). Possible solutions include making the exterior of the crater more erodible than the rim, or improving our parameterization of sediment entrainment and transport.

3. 2D Hydrological Modeling

We used the 2D numerical model BASEMENT [10] to explore the outlet-forming flood. BASEMENT has been used to model dam breach floods in the past [e.g., 11] and has sufficient flexibility to allow its straightforward adoption for Mars problems (changing g, ρ_{sed}, grain size distributions). The physics and geometric assumptions are similar to the 1D model, although the initial geometry has additional free parameters and the sediment transport assumptions are slightly different. Example results of this work are illustrated in Figures 5 and 6 below. One key finding is that most sediment moves as washload.

Figure 5. Two example 2D models of the Jezero outlet-forming flood, showing the changes after 20 days. (a) Increasing grain size / resistence to erosion with depth; (b) Constant grain size to bottom of model domain. Note that the model is setup with higher mesh resolution in the outlet region (hence the large triangles in the lake). The right hand edge of the mesh is a "free flow" boundary for sediment and fluid.



One feature seen in Jezero that the 2D models reproduce is erosion inside the breach on the lake floor, symptomatic of the energetic nature of the flood. In the model, the outlet valley downstream of the breach is generally less entrenched and wider than actually observed. The outlet valley also shows strong evidence of channel migration in the model runs, which is not obvious in observations.

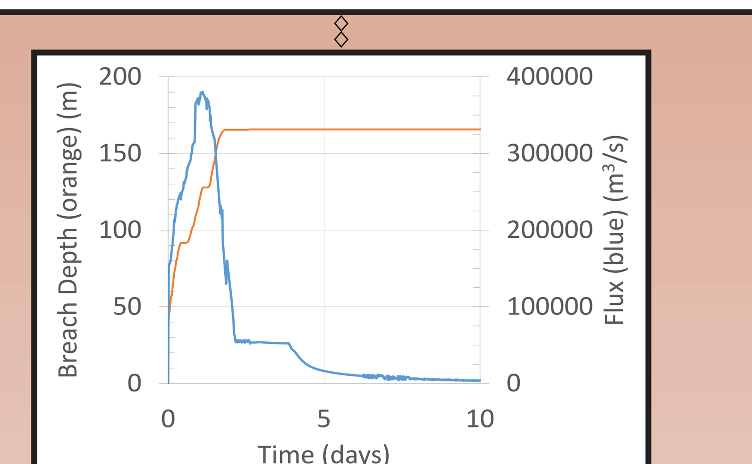


Figure 6. 2D model of the Jezero's outlet forming flood from the run in Fig. 5b. With these parameters, most erosion stalls after a bit more than 2 days when the breach cannot be further incised.

4. Discussion

The questions we ultimately wish to address about Jezero's outlet-forming flood are: (1) What was the flood's hydrograph? (2) What sediment transport and erosion processes were involved? (3) Can Jezero outlet's morphology be explained by catastrophic formation alone, or is longer-term erosion required?

We have made progress towards these questions, but more of the relevant parameter space needs to be explored to be fully satisfied. Peak discharges of ~1-5×10^5 m^3/s are most consistent with the geometry of the Jezero breach. It is evident that large grains (up to coarse gravel) could be moved as washload, at least in the initial flood stages. However, no existing model matches the outlet valley's morphology from catastrophic erosion alone. In the 2D models, the outlet valley downstream of the breach is less entrenched and wider than the canyon that is actually observed (e.g., compare Fig. 4; profile B-B' and Fig. 5).

Ideas for reconciling modeling with observations include: (1) improving sediment transport parameterization, (2) allowing for different erodibility between the crater rim and exterior, or (3) accepting that the outlet valley continued to be eroded well after the breach-forming flood.

4. References

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